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A RADIOFREQUENCY RADIATION EXPOSURE APPARATUS

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FOREWORD

This work was performed in the Radiobiology Division under task No. 775701 during the period May 1969 to February 1970. It was funded initially from the USAFSAM Laboratory Director's Fund and, subsequently, by Procurement Directive RADC/AMD-70-1. The work was requested by the Electronic Systems Division (AFSC).

The animals involved in this study were maintained in accordance with the "Guide for Laboratory Animal Facilities and Care" as published by the National Academy of Sciences–National Research Council.

A large part of the information of this report was provided by the National Bureau of Standards, Boulder, Colo., under a Memorandum of Agreement with the USAF School of Aerospace Medicine. Frank Green and William Jessen were the primary contributors.

The author expresses his appreciation to Glenn Skaggs of the Naval Research Laboratory, Washington, D.C., for his efforts in building and testing the 1:10 scale model for the RF enclosure, for modifying the 50-kwp. pulse transmitter, and for arranging the loan of this equipment to the School.

Special thanks go to John Taboada of the Radiobiology Division for his technical support in the design of the RF enclosure.

This report has been reviewed and is approved.

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ABSTRACT

A radiofrequency radiation exposure apparatus has been developed and placed into operation at the USAF School of Aerospace Medicine, Brooks AFB, Tex. The rectangular coaxial device has dimensions of 4¾ ft. by 9¼ ft. by 30 ft., with a 6-ft.-wide center conductor. It is powered by a 50-kwp. transmitter and operates in a pulsed mode at frequencies of 10.5, 19.27, and 26.6 MHz. Up to 12 animals *(Macaca mulatta)* can be exposed simultaneously to uniform fields ranging in power density from 0.05 to 0.2 w./cm.^{2} The instrumentation system, consisting of portable E- and H-field probes and fixed E-field probes, was developed and calibrated by the National Bureau of Standards. Details of the system design, checkout, and operation are presented.

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I. INTRODUCTION

During the past decade, the power output of radar and communications equipment has increased by more than a factor of ten. Many new-generation radar systems will radiate with average powers in the megawatt range. This trend toward higher powered systems is likely to continue and stimulates a renewed interest in the potential biologic hazards of radiofrequency (RF) electromagnetic radiation.

Beginning in 1956, the Department of Defense established a tri-Service coordinating group to determine the biologic effects of "microwaves" (radiofrequency radiation). Several new research programs were initiated and a series of tri-Service conferences were held to establish "safe exposure levels." The data available did not cover the entire frequency range of interest, but it was decided, finally, to set a "safe exposure level" of 0.01 w./cm.^{2} for all frequencies. This was later modified by such standards as those outlined in AF manual 161-7(1) to permit limited occupancy of areas having power densities of 0.1 w./cm.^{2} These "safe exposure levels" are based on average power and do not take into account peak power since it was felt that the effects were only thermal in nature.

In the past few years, several nonthermal effects of RF radiation have been reported; viz, increases in the clotting time of blood under controlled temperature conditions, molecular resonances which could cause the breakage of molecular bonds when exposed to pulsed energy at high peak power, and "pearl chain formations" observed in human blood at energy levels which are too low to cause heating (2). Also, it is readily recognized that it is not possible to predict the biologic effects associated with a specific system from experiments conducted at different frequencies, power densities, and duty cycles (2).

Many of the new radar systems operate in frequency bands where little experimental work has been accomplished. They have average power outputs in the megawatt range, truly unique duty cycles, and the accepted 0.01 w./cm.^{2} power density isodose line takes in large areas.

The USAF School of Aerospace Medicine was requested to determine if the currently used exposure dose criteria for higher frequencies are also applicable in the 10 to 30 MHz band. In undertaking this work, the development of a special radiofrequency radiation exposure apparatus was required. The device had to operate in the pulsed mode, over a frequency band centered in the 3 to 30 MHz range. It had to provide uniform (far-field) power densities up to 0.1 w./cm.^{2} (0.5 w./cm.^{2} desired) for 6 to 12 animals *(Macaca mulatta)* simultaneously. Suitable instrumentation to monitor the exposures was also required.

II. PROCEDURES

System design

A team of radiofrequency engineering specialists from the Naval Research Laboratory

(Washington, D.C.) and the National Bureau of Standards (Boulder, Colo.) assisted USAF-SAM personnel in selecting and designing the RF enclosure configuration. In addition to the primary requirements listed above, consideration was given to such things as power requirements, cost and ease of construction, size, convenience of use, and shielding effectiveness. Four basic configurations were studied: a parallel plate capacitor, a conventional rectangular waveguide, a standard stripline, and a coaxial transmission line. The standard stripline and parallel plate capacitor were ruled out because of the likelihood of large fringing fields which could cause hazards to personnel and electronic interference. The waveguide also was ruled out because of the large dimensions required at the lower frequencies. It was decided to combine the stripline and coaxial transmission line concepts to produce a rectangular coaxial line. This would provide the advantages of self-shielding and a relatively large, uniform, radiation field.

For the initial checkout of the RF exposure device and the first series of animal experiments, the Naval Research Laboratory loaned to the USAF School of Aerospace Medicine a pulse transmitter (fig. 1), capable of 50-kwp. power. The transmitter consists of four stages of linear amplification with 50-ohm coaxial input and output terminations. The first stage is operated class A with a fixed-grid bias voltage. The three other stages use a pulsed-grid bias voltage. During the intrapulse period, the grid bias voltage is pulsed to a linear operating value. During the interpulse period, the grid bias voltage is well below the

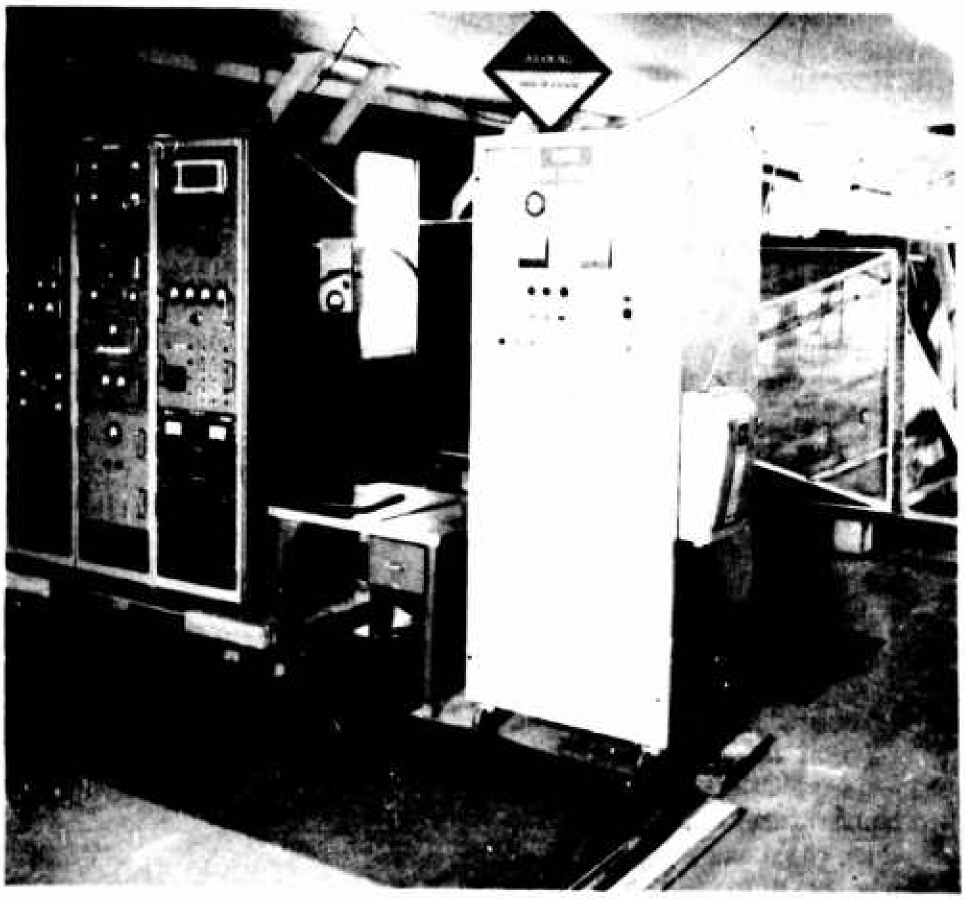

FIGURE 1

Pulse transmitter (50-kwp. power).

cut-off value. This operating method reduces the noise output power during the interpulse period—an initial design requirement for the transmitter (3).

All of the power supplies used are regulated electronically, except for the driver and final-plate supplies. These are variable-voltage supplies with heavy filtering. The final supply is housed in a separate cabinet. Interlock circuits are provided for protection of personnel and equipment (3).

To adapt the transmitter for use in the USAFSAM research program, a low-level exciter and modulator were installed in the transmitter. These units supply the pulsed RF drive to the transmitter and a gating pulse for the grid pulsers (3).

The final dimensions of the RF exposure apparatus (fig. 2) are 4¾ ft. by 9¼ ft. by 30 ft., with a 6-ft.-wide center conductor. The dimensions were selected to conform to the design concepts as presented in references 4 and 5 and to provide a characteristic impedance of 50 ohms to match the output impedance of the transmitter. Personnel at the Naval Research Laboratory also fabricated and tested a 1:10 scale model before the construction of the device at Brooks AFB was begun. The results showed that a ratio of 3:2 for the device width to the center conductor width, and a ratio of 2:1 for the device width to the device height, should produce the proper impedance. Subsequent impedance measurements (using a Boonton RX 250 meter) of the device over the frequency range of 5 to 30 MHz yielded a characteristic impedance of 53 ohms. The transmitted energy is applied from the transmitter to the RF enclosure through a conventional coaxial transmission line (RG 17). The device is terminated in a 15-kw. water-cooled Termaline load resistor.

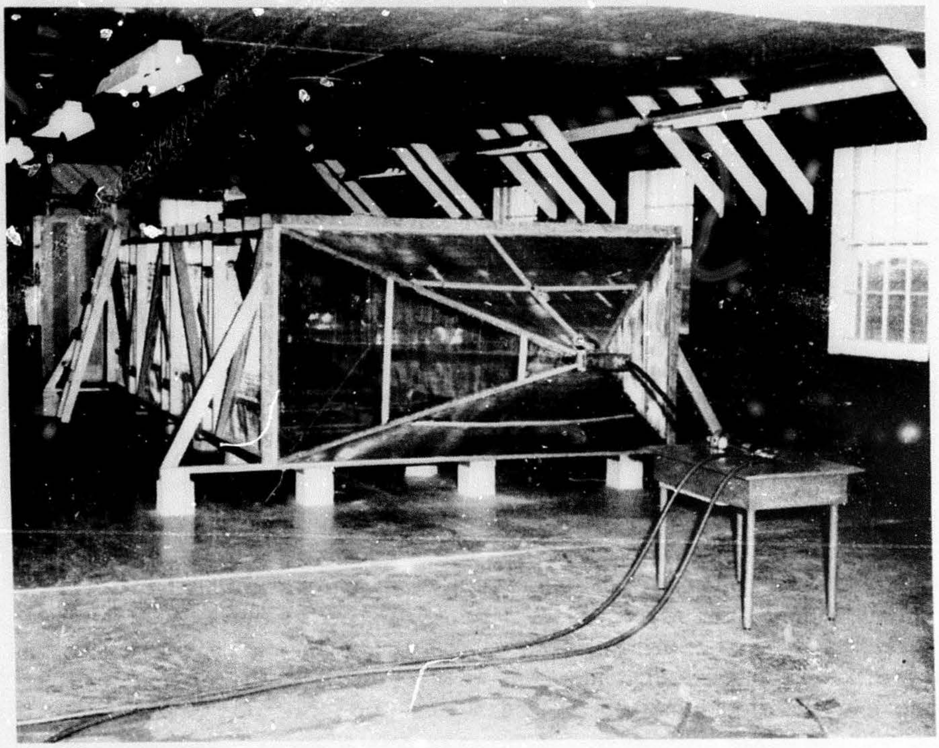

FIGURE 2

Radiofrequency radiation enclosure.

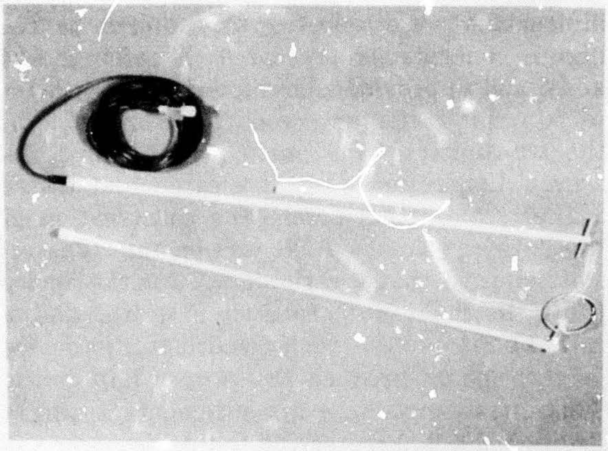

FIGURE 3

Portable probes for E- and H-field measurements.

Instrumentation

Portable, electric (E) field strength and magnetic (H) field strength probes and fixed E-field probes were developed by the National Bureau of Standards to monitor the RF field at any position inside the exposure apparatus (5). The portable E-field probe (fig. 3) consists of a short electric dipole, 10 cm. in overall length. The H-field probe (also shown in fig. 3) consists of a small single-turn loop antenna, 10 cm. in diameter. Each probe has a type 1N4148 silicon-junction semiconductor diode connected across its gap to rectify the induced RF voltage. These dipoles are designed to cover the range from 200 to 2,250 volts per meter, and they produce 1 to 10 volts d.c. output over this range of field strengths. The d.c. output of each probe is transmitted over a special nonmetallic high-resistance transmission line (RG-58A/U) to a Keithley Model 600B electrometer voltmeter and is recorded on a Model 220 Brush recorder. The response and, therefore, the calibration of the E-field probes are frequency independent as long as the length of the dipole does not exceed about 0.01 wavelength and there is no appreciable resistance loading on the dipole output. These conditions are met for the frequencies to be used.

Four fixed probes developed to monitor the E-field inside the RF exposure apparatus during the animal irradiations are mounted at equal intervals along the 20-ft. centerline at the top of the device (fig. 4). These probes are in the form of short monopole antennas, 9 cm. in length, each mounted on a separate small metallic ground plate which, in turn, is clamped against the copper screen of the enclosure. Except for the mechanical and electrical symmetry, the monopole antennas are basically very similar to the previously described dipole antennas. The calibration curve for both E-field probes is shown in figure 5. Like the dipole, the monopole measures the component of the electric field parallel to its axis. The field is vertically polarized along the centerline of the enclosure where these probes are placed. The calibration curve for the portable H-field probe is shown in figure 6.

Measurement of E-field distribution

Measurements of the relative E-field distribution inside the RF exposure device were made by personnel of the National Bureau of Standards (6). The variation in field strength with distance was determined in both the longitudinal (lengthwise) and transverse (crosswise) directions within the enclosure. The electric field, E, is polarized vertically in the region near the center of the enclosure and gradually becomes polarized horizontally as one moves in the transverse direction toward the gap at the side. Both the vertical and horizontal components of the E-field were measured at each point where data were taken, and the total electric field was plotted on the field-distribution curves shown in figures 7 and 8.

For these tests, the enclosure was driven by a low-power 50-w. continuous-wave transmitter and terminated in a coaxial power load having a resistance of 50 ohms, the characteristic impedance of the enclosure. The tests were made at a frequency of 21 MHz which was approximately the center of the frequency range of interest (10 to 30 MHz). The relative field distribution is independent of the magnitude of the test field and the wave-type used (continuous or pulse-modulated) so long

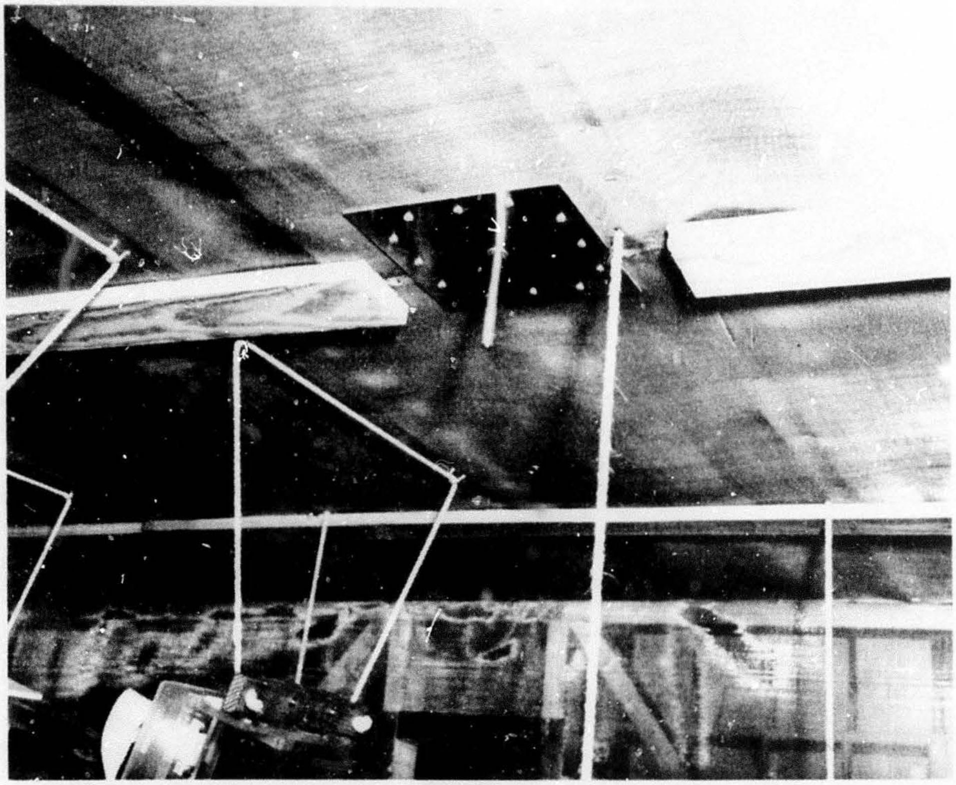

FIGURE 4
Fixed E-field monopole probe.

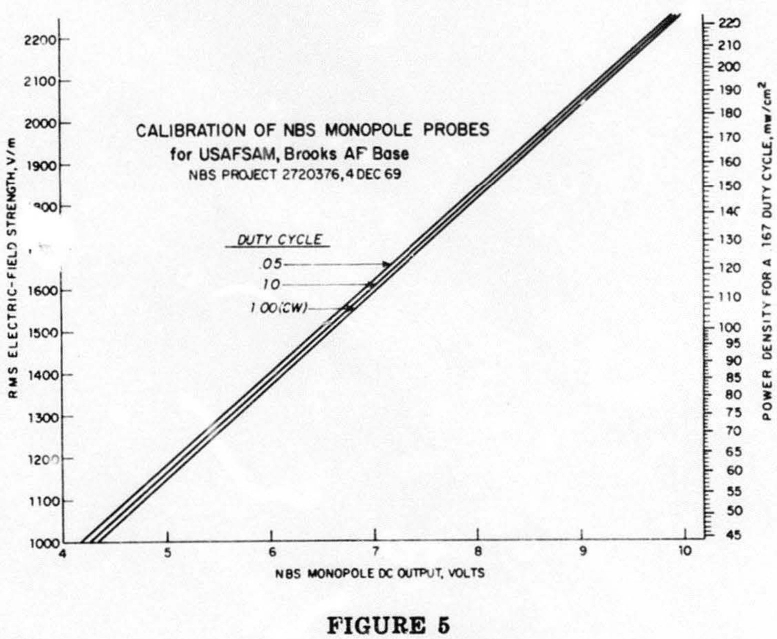

FIGURE 5
E-field probe calibration.

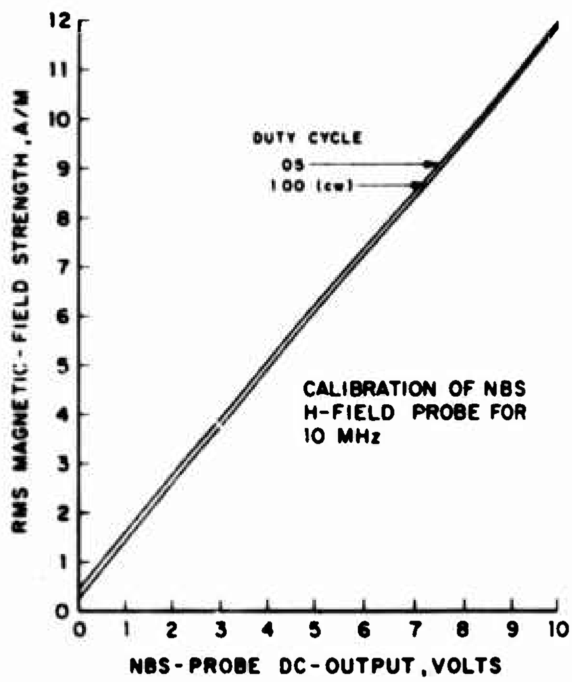

FIGURE 6

H-field probe calibration.

as the enclosure and its terminating load remain linear over the range of RF power used. The field distribution also will be essentially independent of frequency over the above frequency range since the reflected power measured was quite low.

Figure 7 shows the relative variation in electric-field strength with distance lengthwise along the centerline of the enclosure approximately halfway between the center strip and the top of the enclosure. The distribution shows that the variation in field strength does not exceed approximately 2.5% (0.2 dB) along the 20-ft. enclosure. The standing-wave ratio (SWR) along the enclosure, therefore, appears to be approximately 1.05. When the SWR was measured using a Bird Thruline wattmeter, a reflected power of 0.13 w. was observed for a forward power of 50 w., giving an SWR of approximately 1.10. This SWR appears to be entirely satisfactory for the intended use of this enclosure.

Figure 8 shows the relative variation in electric-field strength with distance across the enclosure at three heights—4, 8, and 12 inches—above the center strip for a position 10 ft. back from the taper at the load end of the enclosure. The relative variation in the field is approximately the same at any position along the enclosure. The field can be seen to

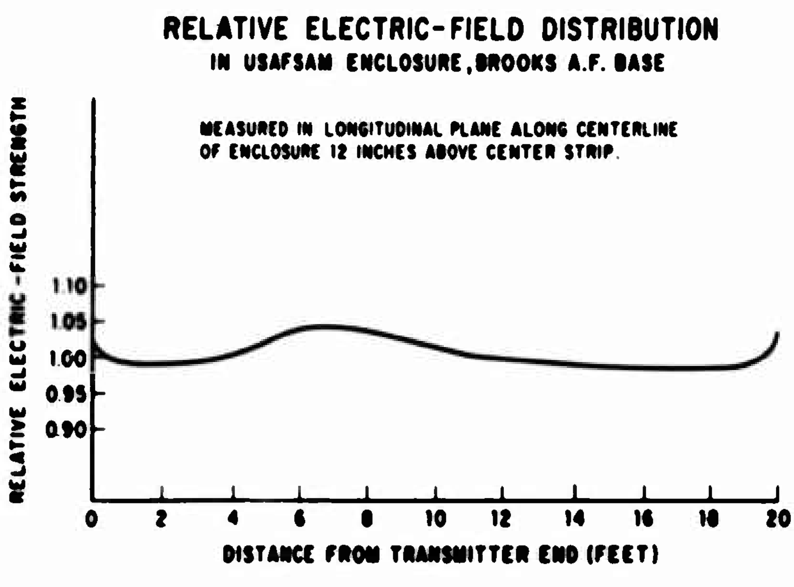

FIGURE 7

Relative intensity of E-field along 20-ft. centerline.

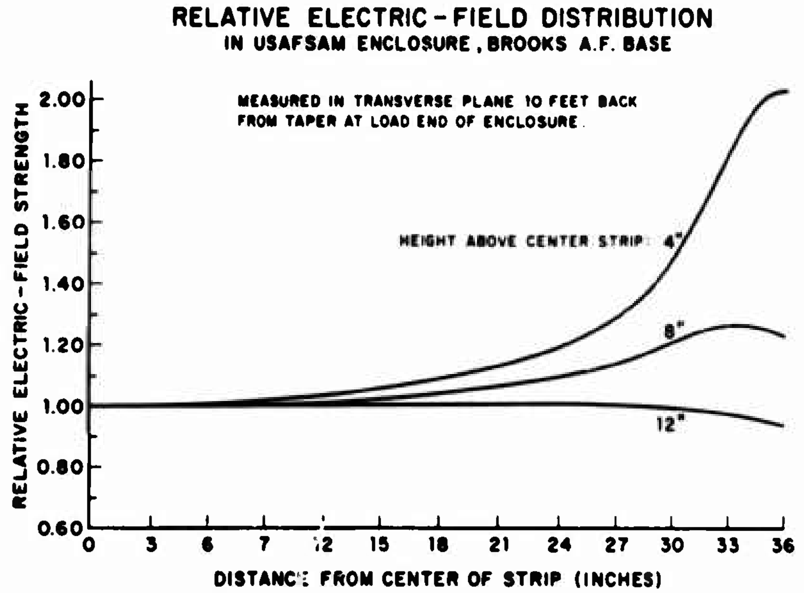

FIGURE 8

Relative intensity of E-field from center to edge of 6-ft.-wide center conductor.

be constant within ±0.5 dB throughout the central 4 ft. of the 6-ft.-wide center strip (for the central 12-in. regions between the center strip and the top or bottom of the enclosure; e.g., the region extending from 8 in. above the center strip to 8 in. down from the top).

With the completion of these field measurements and the final operational checkout of the pulse transmitter, the RF exposure apparatus was declared operational.

III. EXPERIMENTATION

Initial experiments

Two types of animal experiments were initiated. The first involves single passive radiation exposures of up to 12 animals *(Macaca mulatta)* simultaneously at one frequency (either 10.5, 19.27, or 26.6 MHz) with detailed pre- and postexposure investigations to observe any RF-induced biologic changes. Hematology studies include white blood cell count, differential count, and hematocrit value. Biochemistry studies include serum glutamic oxalacetic transaminase, serum glutamic pyruvate transaminase, lactic dehydrogenase, blood urea nitrogen, serum glucose, and electrophoresis of serum proteins. After sacrifice of each animal (following 28-day postexposure survival or earlier death), autopsies are performed for gross pathologic observations, and selected tissues are processed for histopathologic study. These same studies are performed on 12 control animals for each 12 irradiated. The exposures are made at one of three frequencies (10.5, 19.27, or 26.6 MHz) and at a power density between 0.05 and 0.2 w./cm.^{2} for 30 to 60 minutes.

The second type of experiment involves instrumenting animals for temperature and electrocardiogram (ECG) measurements. The animals are placed in the exposure device and the power density varied to observe any changes in these physiologic parameters. Future experiments will include a series of chronic exposures to better simulate the environmental situation of personnel working in and around high-frequency radar and communication systems.

IV. CONCLUSION

The radiofrequency electromagnetic radiation exposure apparatus described herein is believed to be the first of its kind developed to study the potential biologic hazards of pulsed high-frequency (3 to 30 MHz) RF radiation. All of the essential design requirements were met, and the first animal experiment was completed.

The currently assigned "personnel exposure criteria" for high-frequency (3 to 30 MHz) pulsed radar systems are extrapolated from research conducted at other frequencies and, in most instances, for different modes of transmission. The experimental data to be obtained with the use of this exposure apparatus should provide new guidelines for establishing more realistic "personnel exposure criteria" for many of the new-generation radar systems and comparable communications systems.

Recognizing the frequency and power limitations of the present transmitter, plans are being made to install more versatile equipment with the present RF enclosure to provide continuous frequency coverage over a wider range, higher average power output, and both continuous and pulsed modes of operation.

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13. ABSTRACT

A radiofrequency radiation exposure apparatus has been developed and placed into operation at the USAF School of Aerospace Medicine, Brooks AFB, Tex. The rectangular coaxial device has dimensions of $4\frac{3}{4}$ ft. by $9\frac{1}{4}$ ft. by 30 ft., with a 6-ft.-wide center conductor. It is powered by a 50-kwp. transmitter and operates in a pulsed mode at frequencies of 10.5, 19.27, and 26.6 MHz. Up to 12 animals (Macaca mulatta) can be exposed simultaneously to uniform fields ranging in power density from 0.05 to 0.2 w./cm.^{2} The instrumentation system, consisting of portable E- and H-field probes and fixed E-field probes, was developed and calibrated by the National Bureau of Standards. Details of the system design, checkout, and operation are presented.

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